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14. ABSTRACT

We have evaluated the performance of a new type of Fe spin-LED in which recombination takes place in InAs monolayers grown at the intrinsic region of an n-i-p AlGaAs(n)/GaAs(i)/AlGaAs(p) diode. The intrinsic region is a wide GaAs quantum well. The InAs layer is known as the "wetting layer" (WL). The new WL spin-LEDs were found to have the same high circular polarization as the more conventional Fe spin-LEDs , but differ in one very important aspect: They are one order of magnitude brighter than their conventional counterparts. As a result, the WL spin-LEDs function reliably at room temperature (the conventional spin-LEDs don't).

15. SUBJECT TERMS

spin light emitting diodes, electrical injection of spin polarized carriers, spintronics

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Final Progress Report for Contract N00014-05-1-0564

Performance Optimization of Fe-Based Light Emitting Diodes

A new type of spin light emitting diode (spin-LED) has been developed in collaboration with Dr. B.T. Jonker's group at NRL. In the past we have investigated spin-LEDs in which the electron-hole recombination takes place either in a GaAs quantum well (QW)[1-3]or in an InAs quantum dot (QD)[4]. The InAs QD growth proceeds as follows: InAs is deposited on GaAs and initially forms a two-dimensional layer which is highly strained due to the large lattice mismatch between GaAs and InAs. This layer, known as "wetting layer" (WL) , has a critical thickness of 1.7 monolayers. The InAs QDs are grown on the WL using an indium flash procedure. Optical pumping experiments showed that the WL has a strong polarization of 30% which remains constant in the 5 K-100 K temperature range. This polarization corresponds to a ratio $\frac{\tau_R}{\tau_S}$ of the radiative and the spin relaxation time of approximately 1. This finding prompted us to investigate spin-LEDs which incorporate only the InAs WL and explore their characteristics. What we refer below as "WL" is in reality a narrow InGaAs quantum well (well width 3-4 nm) with an Indium composition in the range of 25 – 35% [5]. The band structure diagram of an Fe-spin LED which incorporates three WL at the center of a wide undoped (40 nm) GaAs quantum well is shown in fig.1. The $Al_{0.1}Ga_{0.9}As$ barrier to the left of the WLs was doped n-type, while the $Al_{0.3}Ga_{0.7}As$ barrier to the right was doped p-type. The leftmost 15 nm of the n-type $Al_{0.3}Ga_{0.7}As$ barrier was heavily doped ($n = 1\times10^{19}$ cm^{-3}) to form a Schottky barrier with the 10 nm Fe contact [1]. An external magnetic field B is applied perpendicular to the Fe contact to saturate its out of plane magnetization. Under these conditions spin polarized electrons (predominantly in the spin down $m_S = -1/2$ state) from the Fe contact tunnel through the reversed biased Fe/ $Al_{0.3}Ga_{0.7}As$ Schottky barrier; unpolarized holes are injected from the p-type GaAs buffer layer. Electrons and holes are captured by the narrow QWs formed at the WLs and recombine emitting photons which are circularly polarized as σ_+. The circular

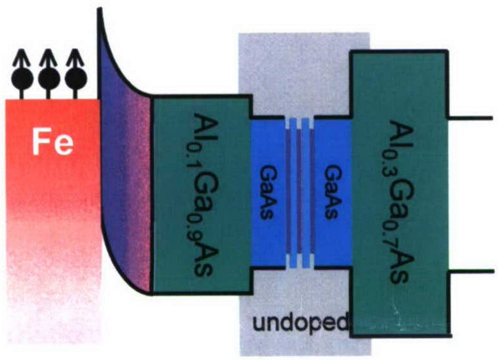

Fig.1: Band diagram of an Fe-spin LED in which three WL are incorporated at the center of a wide (400 nm) GaAs QW

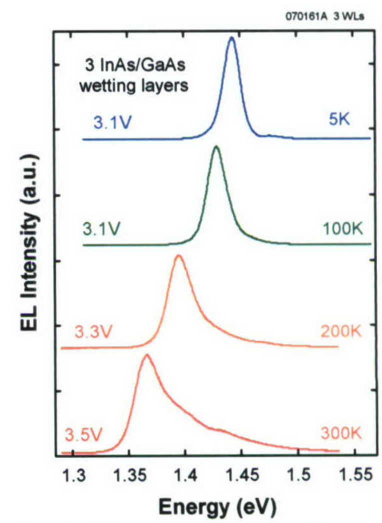

Fig.2: EL spectra from an Fe spin-LED that incorporates 3 WL at T = 5, 100, 200 , and 300 K

polarization P_{opt} of the emitted light is defined as: $P_{opt} = \frac{I_+ - I_-}{I_+ + I_-}$. Here I_+ (I_-) is the intensity of the σ_+ (σ_-) component of the emitted light which is due to the recombination of spin -1/2 (+1/2) electrons with spin -3/2 (+3/2) heavy holes [6]. The light hole states are pushed down in energy by confinement and do not participate in the recombination process. The spin polarization P_e of the electrons in the WL can be determined using the equation: $P_e = P_{opt}\left(1 + \frac{\tau_R}{\tau_S}\right)$

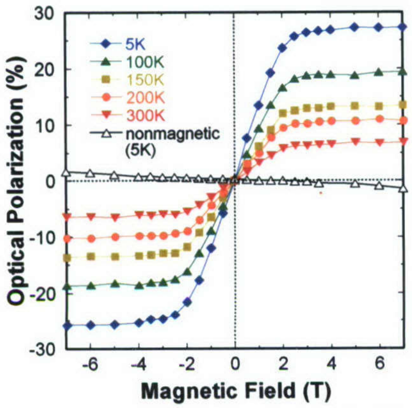

Fig.3: Circular polarization of the EL plotted as a function of magnetic field applied perpendicular to the device layers for a WL Fe spin-LED at T = 5, 100, 150, 200, and 300 K

The electroluminescence intensity from WL spin-LEDs is typically one order of magnitude larger that the EL from conventional spin-LEDs in which recombination takes place in a quantum well. Even though only a small fraction of the conventional QW spin LEDs emits at room temperature, all WL spin-LEDs show room temperature emission. This is illustrated in fig.2 in which the EL spectra from a spin-LED that incorporates three wetting layers is shown for T = 5, 100, 200, and 300 K.

The circular polarizarion P_{opt} from an Fe spin-LED that incorporates a WL is plotted in fig.3 as function of applied magnetic field for T = 5, 100, 150, 200, and 300 K. At T = 5 K the polarization is high (26%) and decreases slowly with increasing temperature in the 5-100 K temperature range. For T > 100 K the drop in P is more steep, but even at room temperature we observe clear spin injection from Fe. All curves mirror the out of plane magnetization of Fe which increases with B and saturates at 2.5 tesla. In fig.3 we also include the polarization from an LED with a non-magnetic contact to exclude any spurious effects.

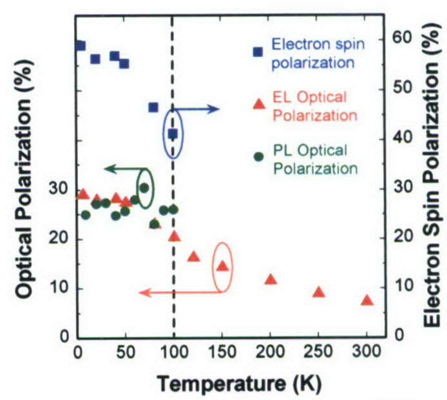

Fig.4: Temperature dependence of EL circular polarization P_{opt} (red triangles), circular polarization of PL under optical pumping (green circles), and electron spin polarizarion P_e (blue squares) for a WL spin LED at 3 tesla.

In fig.4 we summarize the temperature dependence of the optical polarization P_{opt} (left vertical axis) as well as the WL electron spin polarization P_e (right vertical axis) as function of temperature. The optical polarization was measured from the EL of an actual spin-LED (red triangles) or under optical pumping of a reference heterostructure (green circles). The intensity of the PL in the latter experiment becomes too low for T > 100 K for reliable measurements of P_{opt}. In the 5-100K temperature range for which we have data from both experiments (EL and

PL) the dependence of P_{opt} on T is comparable. The blue squares in fig.4 represent P_e which is calculated form P_{opt} using the equation" $P_e = P_{opt}\left(1+\frac{\tau_R}{\tau_S}\right)$. The ratio $\frac{\tau_R}{\tau_S}$ is determined from the optical pumping experiment. Rather large (over 50%) electron spin polarizations have been measured in the 5-100K temperature range.

In conclusion, the properties of a new type of spin-LED, which incorporate InAs wetting layers, have been explored. These LEDs are more efficient that conventional spin-LEDs and operate reliably at room temperature.

References

1. Hanbicki, A.T., B.T. Jonker, G. Itskos, G. Kioseoglou, and A. Petrou, *Efficient electrical spin injection from a magnetic metal/tunnel barrier contact into a semiconductor.* Applied Physics Letters, 2002. **80**(7): p. 1240-1242.
2. Li, C.H., G. Kioseoglou, O.M.J. van 't Erve, A.T. Hanbicki, B.T. Jonker, R. Mallory, M. Yasar, and A. Petrou, *Spin injection across (110) interfaces: Fe/GaAs(110) spin-light-emitting diodes (vol 85, pg 1544, 2004).* Applied Physics Letters, 2004. **85**(17): p. 3939-3939.
3. Kioseoglou, G., A.T. Hanbicki, B.T. Jonker, and A. Petrou, *Bias-controlled hole degeneracy and implications for quantifying spin polarization.* Applied Physics Letters, 2005. **87**(12): p. 122503(1-3).
4. Li, C.H., G. Kioseoglou, O.M.J. van 't Erve, M.E. Ware, D. Gammon, R.M. Stroud, B.T. Jonker, R. Mallory, M. Yasar, and A. Petrou, *Electrical spin pumping of quantum dots at room temperature.* Applied Physics Letters, 2005. **86**(13): p. 132503(1-3).
5. Offermans, P., P.M. Koenraad, R. Notzel, J.H. Wolter, and K. Pierz, *Formation of InAs wetting layers studied by cross-sectional scanning tunneling microscopy.* Applied Physics Letters, 2005. **87**(11): p. -.
6. Jonker, B.T., A.T. Hanbicki, Y.D. Park, G. Itskos, M. Furis, G. Kioseoglou, A. Petrou, and X. Wei, *Quantifying electrical spin injection: Component-resolved electroluminescence from spin-polarized light-emitting diodes.* Applied Physics Letters, 2001. **79**(19): p. 3098-3100.

Presentations and Publications

The results of this work have been reported in two conferences and in one Journal paper. These are listed below:

1) "Electrical Spin Injection into InAs Wetting Layer", C.H. Li, G. Kioseoglou, A.T. Hanbicki, B.T. Jonker, M. Yasar, and A. Petrou, 52^{nd} Conference on Magnetism and Magnetic Materials, November 5-9, 2007, Tampa FL.

2) "Electrical Spin Injection into InAs Wetting Layer", C.H. Li, G. Kioseoglou, A.T. Hanbicki, R. Goswami, C.S. Hellberg, B.T. Jonker, M. Yasar, and A. Petrou, the 2008 March Meeting of the American Physical Society, March 10-14, 2008, New Orleans, Lousiana.

3) "Electrical Spin Injection into the InAs/GaAs Wetting Layer", C.H. Li, G. Kioseoglou, A.T. Hanbicki, R. Goswami, C.S. Hellberg, B.T. Jonker, M. Yasar, and A. Petrou, Accepted for publication in Applied Physics Letters.